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Growth and fruit characteristics of edible cactus (*Opuntia ficus-indica*) under salt stress environment

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ABSTRACT

The advancing desertification coupled with increasing problems of salinity and drought warrants the development of appropriate technologies and identification of the crops capable of sustaining valuable food and fodder production in arid and semi-arid areas. Edible cactus (*Opuntia ficus-indica*) can provide a large range of commodities in the areas with scarce and degraded available resources. Thus, it has raised renewed interest and hope to attain potential productivity in the stressed areas. A sizeable part of India is affected by salt and drought conditions, thus, potentially suitable for cultivation of edible cactus to generate alternate source of livelihood and employment. There is a need to generate information on its critical limits of salinity tolerance and ability to mitigate the salt stress in these areas. A pot experiment was conducted at Central Soil Salinity Research Institute, Karnal during 2008-2011. Clone 1280 was grown using two quality irrigation waters in combination with three soil salinity levels. The observations on growth suggests that the plant is moderately tolerant to soil salinity and most of the growth parameters, viz., number of sprouts, plant height and number of cladodes started declining at 6 dS m^{-1} soil salinity. No significant adverse effect of saline water irrigation was found on survival of cactus at EC_{iw} 4 dSm^{-1} except reduction in the number of sprouts produced. The above ground parts of biomass production were found sensitive at EC_e 6 dSm^{-1} soil salinity, while root biomass production was more sensitive to saline water irrigation rather than soil salinity. Finally, fruit quality characteristic of promising edible cactus clones and their potential of acceptability as a palatable fruit among general public was evaluated.

Key words: edible cactus, *Opuntia ficus-indica*, clone, salinity, irrigation water, fruit characteristics

Introduction

Cactus (*Opuntia ficus-indica*) has been commercially exploited as fruit, vegetable, forage, energy, medicinal and dye yielding crop in arid and semi-arid areas of world. The countries where cactus is commonly cultivated are Mexico, Brazil, Argentina, South Africa, Israel, USA, Italy and many other Latin American countries. Cactus was identified as a potential crop for arid and semi-arid regions of world (Lahsasni *et al*., 2003). The cultivation of cactus as a commercial crop is little known in Indian sub-continent. Only the wild cactus is found growing in wastelands, as hedge around agricultural fields to protect crops from wild life and as a decorative plant in parks and home gardens. Cactus is used for several purposes but the most significant uses include: as a fruit and vegetable for human consumption (Snyman, 2004), forage for livestock and as a red dye. Several other minor uses of cactus are: control of diabetes, ethanol production, as live fence and for industrial use of its *galactomannan* mucilage and cosmetics such as shampoo, cream, and body lotions, etc. (Felker *et al*., 1997; Feugang *et al*., 2006; Singh, 2006). Owing to its high water use efficiency per unit dry matter production, because of crassulacean acid metabolism (CAM), photosynthetic pathway, the plant has ample scope of its introduction and cultivation in rain-fed and dry land areas of India, where 67 per cent of the poor rural population is settled. Cactus has special significance in drought prone area of the country where cactus plantation will help in augmenting food and fodder requirement and thus halting migration of cattle and human beings to other areas. Planting of trees and bushes like cactus on all kinds of wastelands, on field boundaries, road and railway track sides etc. in all drought prone and salt-affected areas of the country has tremendous potential to generate livelihood opportunities in resource poor conditions. The low cost of cactus establishment and production as well as its tolerance to drought make it well suited to become a viable future industry in rain-fed areas. In addition to its remarkable value as cattle and human food, it has a potential for soil and water conservation when planted on slopes in the hilly terrace in the rain-fed areas of the country.

Plenty of literature available on physiology of *Opuntia ficus-indica* and its response to the environment, points towards its increasing economic importance for fruit, fodder and industries (Nobel and Zutta, 2008; Felker *et al.*, 2005; Galizzi *et al.*, 2004; Felker and Inglese, 2003; Anderson, 2001; Inglese *et al.*, 1995). Being drought tolerant prickly pears are suited to those areas, where rainfall is scarce and unreliable, and irrigation water is limited which causes upward thrust of salts of these soils in most parts of the year. Due to the limitation of the feed resource as a result of rangeland degradation, there is more concern for cactus pear, which has ability to produce satisfactory amounts of fruits and fodder under the prevailing stress conditions (Felker and Inglese, 2003). The optimum conditions for its growth are available in summer rainfall regions having average rainfall between 300-600 mm. Hot sunny days and cool dry winter where temperature do not fall below 5^o C are most suitable for cactus production. Cactus thrives best on sandy and sandy loam soils. However, it does well even on heavy soils with adequate drainage. Gravelly or stony lands especially at the foot hill slopes are also suitable. Further, it thrives well on slightly alkaline soils rich in calcium and potassium. This indicates that any soil which is not suitable for other crops can be planted to cactus provided that area is not subject to prolonged waterlogging. A large part of India is, thus, suitable for its cultivation to generate alternate source of livelihood and employment. There are more than 150 districts in India which are highly drought prone; this crop has tremendous potential to augment forage production in those areas.

In arid and semi-arid regions, aridity is also associated with soil and ground water salinity. There are only few studies describing adaptations of *Opuntia* to water scarcity and its responses to salinity are not well quantified (Murillo-Amador *et al.*, 2001; Pimienta-Barrios *et al.*, 2002). Establishment of cactus pear under salt affected arid conditions is very critical for its survival, growth and development. In general, cactus pear is found growing under resource scarce conditions. So to realize the full potential of cactus pear in arid zones, there is a need to generate information on its critical limits of salinity tolerance and ability to mitigate the salt stress.

Materials and methods

A pot experiment was conducted at Central Soil Salinity Research Institute, Karnal, situated at 29^{o}42' N latitude and 76^{o}57' E longitude and an altitude of 243 meter above mean sea level. Annual rainfall was 68, 48 and 110 cm for the year 2008, 2009 and 2010, respectively. Clone 1280 (fruit) was planted in 30 kg capacity ceramic pots for studying the critical limits of soil and irrigation water salinity. The pots were uniformly filled with sandy loam soil (pH 7.8, organic matter 2.8 g kg^{-1} soil, clay 14%) having three salinity levels viz; normal (EC$_e$ 0.6 dS m^{-1}), EC$_e$ ~ 4 & 6 dS m^{-1}. The pots were maintained by mixing required quantity of three salts i.e. NaCl, $MgSO_4.7H_2O$ and $CaCl_2.2H_2O$ in the ratio of 30: 2: 4 on the soil weight basis giving three wetting and drying cycles and were adjusted to required salinity. Two quality irrigation waters EC$_e$ ~ 2 & 4 dS m^{-1} salinity were applied. The experiment was laid out in split plot design with three replications. The plants were uniformly supplied with N, P and K dose (at the rate of 100, 50 and 100 kg ha^{-1}, respectively in addition to 10 t ha^{-1} FYM. The NPK were supplied through di-ammonium phosphate, urea and muriate of potash. Observations were recorded on survival at the beginning, number of new sprouts, plant height (cm) and numbers of cladodes for each plant were recorded at six months interval for three years and final plant height, number of cladodes and fresh biomass of shoot and root were recorded in 2012 after five years of planting by destructive sampling. For observing fruit characteristics, ripen fruits were harvested from four promising clones (1270, 1271, 1280 and 1287) and their length, diameter, weight, moisture (%), TSS (^{o}B) and phosphorus nitrogen (p/n %) ratio were measured. The ripe fruits of these clones were given to 527 persons in years 2008, 2009 and 2010 for taste analysis based upon taste and sweetness. Each individual varying in age from 28 to 50 years was asked to give a score on a 0 to 10 scale. The data presented are either average of three years (Fig.1) or after five years of planting (Fig. 2). Analysis of variance at 95% confidence interval was applied to each data set to assess the effects of treatments on all recorded parameters. Each variable was analysed statistically by 'two way ANOVA' using Genstat release 13 (GenStat® 13th Edition, VSN International Ltd., Lawes Agricultural Trust, Rothamsted, UK) statistical software. To determine critical differences, Fisher's protected least significant difference test was used. The method of Fisher (1949) was used in order to determine the least significant difference (*lsd*).

Results and discussion

Establishment and growth

Results of three years of experimentation showed that cactus clone 1280 had better (although not significant) survival of 84 % (average) when irrigated with water of 2 dS m^{-1} salinity as compared to 81% survival under 4 dS m^{-1} salinity irrigation water (Fig.1A). This slight reduction in survival percentage was also observed in plants grown in soil of EC$_e$ 4 dS m^{-1} salinity (82%) and (79%) in 6 dS m^{-1} soil salinity as compared to normal (0.6 dS m^{-1}) soil (86%). Perusal of data presented in Figure1A showed reduction of survival (%) in various levels of soil and water salinity (data presented are average of three years). The average number of new sprouts emerged at six monthly interval were reduced significantly in various treatments of water quality (p= 0.002) and soil salinity (p =0.001) (Fig.1B). On an average 1.08 new sprouts were emerged in every six months in 2 dS m^{-1} salinity water irrigation treatment, that was significantly higher (*lsd* 0.21) than 4

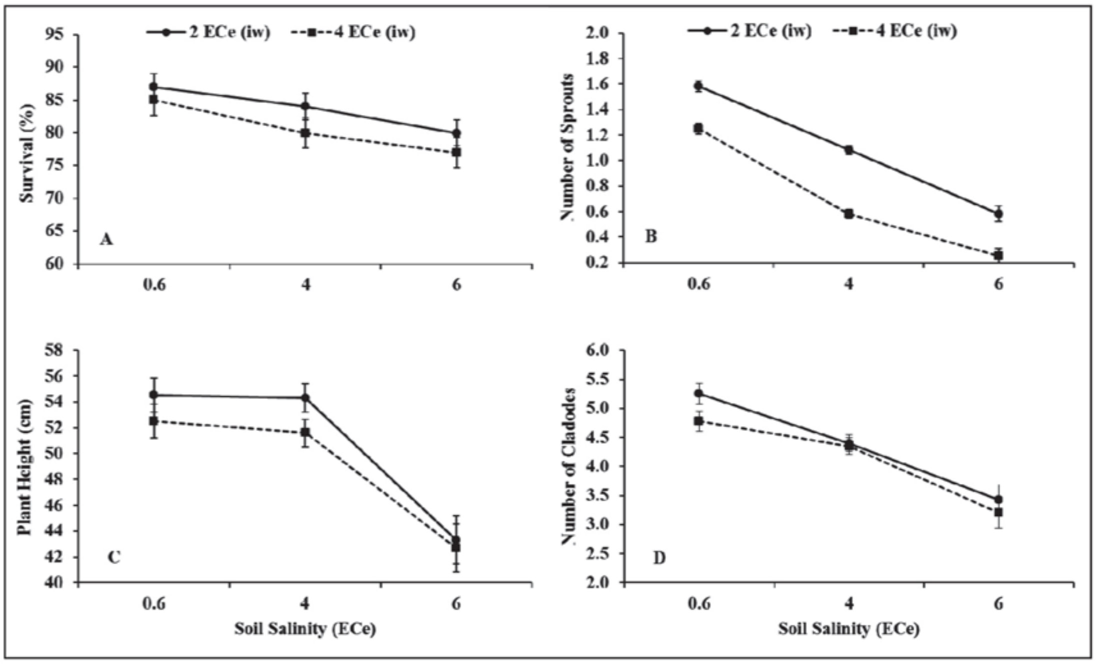

Fig. 1. Effect of soil salinity (EC_e~ 0.6, 4.0 and 6.0 dS m^{-1}) and water quality (EC_{iw}~ 2.0 and 4.0 dS m^{-1}) on (A) Survival (%), (B) Number of sprouts, at beginning and (C) Plant height, (D) Number of cladodes of *Opuntia ficus-indica*, after three years of growth under The vertical bars are standard error of means (SEm±) of respective mean values.

dS m^{-1} water quality treatments. Among different soil salinity treatments, the highest numbers of sprouts (1.42) emerged in normal soils (0.6 dS m^{-1}) and sprouts emergence was significantly (*lsd* 0.26) reduced in 4 dS m^{-1}, (0.83) and further in 6 dS m^{-1} soil salinity (0.42) (Fig.1B).

Plant height was reduced significantly (p=0.007) with increase in soil salinity (EC_e) from normal (0.6 dS m^{-1}) to 4.0 dS m^{-1} and then to 6.0 dS m^{-1} though this reduction was not significant (p=0.802) in case of saline water treatments (Fig.1C). The average plant height in 2 and 4 dS m^{-1} salinity waters were 50.7 cm and 49.9 cm, respectively (*lsd* 6.18). There was a reduction in plant height from 54.4 cm to 53.5 cm in soil salinity ECe 4 dS m^{-1} as compared to normal (0.6 dS m^{-1}) and there was a significant (*lsd* 7.57) reduction to 43 cm in 6.0 dS m^{-1} soil salinity treatment (Fig.1C).

Again, the three years average of number of cladodes produced every six months were reduced significantly (p=0.008) with the increase in soil salinity and a non-significant (p=0.549) reduction when irrigation water salinity increased from 2.0 dS m^{-1} to 4.0 dS m^{-1} (Fig.1D). The number of cladodes produced was reduced from 5.02 in normal (0.6 dS m^{-1}) to 4.38 in 4.0 dS m^{-1} and further to 3.32 in 6.0 dS m^{-1} soil salinity (*lsd* 1.03). The reduction in number of cladodes was from 4.36 to 4.11(*lsd* 0.84) in 2.0 and 4.0 dS m^{-1} salinity irrigation water (Fig.1D).

Opuntia species are reported to be tolerant to water stress but sensitive to high salinity (Nerd *et al*., 1991; Murillo-Amador *et al*., 2001). However, plant responses to salinity may differ with genotype and several authors reported the ability of the species to survive and grow in saline environments (Maas and Grattan, 1999). In the present study the survival of cactus clone did not reduce drastically up to 6.0 dS m^{-1} soil salinity and 4.0 dS m^{-1} of water salinity. The higher survival rate of prickly pear in moderate salinity proved its ability to proliferate in saline conditions. According to Nerd *et al*. (1991), salinity did not play a significant role in fruit yield and plant height. Nobel *et al.,* (1984) reported the survival of *C. validus* on temporarily highly saline soils. In present study plant height, number of sprouts, and cladodes reduced significantly in 6 dS m^{-1} of soil salinity, whereas, irrigation water salinity up to 4.0 dS m^{-1} had no adverse significant effect on these parameters except number of sprouts emerged which reduced significantly with the application of saline water after three years of growth (Fig.1). Decrease in plant height of clone 1280 might have resulted from the excessive accumulation of salts in cladodes to toxic levels. Inward ion retention through the selective ion transport across the roots, and the special possibilities of carbon budgeting as a result of CAM (Nobel *et al.,* 1984) would be the possible reasons for cactus to be a productive crop on moderately saline soils. The salt build-up in soil at 6.0 dS m^{-1} of salinity affected plant processes adversely through osmotic effects and ionic imbalances; however, those could be offset by adequate supply of nutrients.

Growth and biomass (after five years)

After five years, the plants under various treatments were differed in plant height. Plant height was reduced (although not significantly; p=0.293) with increase in water salinity from 2 to 4 dS m^{-1} and there was a significant (p=0.037) reduction when soil salinity increased (EC_e) from normal (0.6 dS m^{-1}) to 6.0 dSm^{-1}, although treatment with 4.0 dS m^{-1} soil salinity was at par with normal soil treatment (Fig. 2A). The average plant heights in 2 and 4 dS m^{-1} water were 96.8 cm and 92.9 cm, respectively (*lsd* 7.48). There was a reduction in plant height from 100.7cm in normal (0.6 dS m^{-1}) to 95.5cm in 4.0 dS m^{-1} soil salinity, however, reduction in plant height to 88.5 cm reached significant (*lsd* 9.17) levels in 6.0 dS m^{-1} soil salinity treatment (Fig. 2A).The number of cladodes produced after five years were reduced with the increase in soil salinity and also when irrigation water salinity increased from 2.0 to 4.0 dS m^{-1} (Fig. 2B), although, this reduction was statistically not significant (p=0.09 and 0.368, respectively). The number of cladodes produced was reduced from 13 in normal (0.6 dS m^{-1}) to 12.5 in 4.0 dS m^{-1} and further to 10.96 in 6.0 dS m^{-1} soil salinity (*lsd* 1.90) levels. The reduction in number of cladodes in 2.0 dS m^{-1} and 4.0 dS m^{-1} salinity water irrigation was from 12.5 to 11.81 (*lsd* 1.55) (Fig. 2B) which is statistically non significant.

Fresh above ground biomass was reduced significantly with increased soil salinity (p=0.001), but this reduction was not significant (p=0.356) for saline water irrigation treatments (Fig. 2C). The highest shoot biomass (5.05 kg) was produced with normal salinity (0.6 dS m^{-1}), significantly reduced to 4.15 kg in EC_e 4.0 dS m^{-1} and further to 3.69 kg in EC_e 6.0 dS m^{-1} soil salinity (*lsd* 0.69). The reduction in fresh shoot biomass in EC_e 4.0 dS m^{-1} salinity water irrigation was from 4.42 (in ECe 2.0 dS m^{-1}) to 4.17 kg (*lsd* 0.56) (Fig. 2C). The reduction in fresh root biomass was not significant (p=0.152) in various soil salinity treatments, but significant (p=0.032) in saline water irrigation treatments (Fig. 2D). The root biomasses produced in normal (0.6 dS m^{-1}), EC_e 4.0 and 6.0 dS m^{-1} soil salinity treatments were 0.58, 0.52 and 0.49 kg, respectively (*lsd* 0.097). There was a significant reduction (*lsd* 0.079) in root biomass (0.58 kg) at EC_{iw} 2.0 dS m^{-1} to biomass (0.49 kg) at 4.0 dS m^{-1} salinity of irrigation water.

The plant height and number of cladodes reduced significantly in 6 dS m^{-1} of salinity, whereas, irrigation water salinity up to 4.0 dS m^{-1} had no significant effect after five years of growth (Fig.2A,B). The possible reasons and processes of this discussed in earlier section (establishment and growth) also explain for the reduction in plant growth after five years. Acclimation of cell sensitivity to salinity, a key short-term strategy for ecological survival of plant and a crucial feature for deciding where cacti can be successfully cultivated, was similar for stems and roots (Nobel and Zutta, 2008). The accumulation process involves many factors (Chetti and Nobel, 1987; Thomashow, 1999). For example, the total fresh biomass accumulation was a function of number of sprouts emerged, plant height gained and number of cladodes produced as interactive response of these parameters in different salinity treatments in the study (Fig. 2C).The total biomass accumulation is related to the cladode surface area (Garcia de Cortazar and Nobel, 1992).The lower above ground biomass accumulation

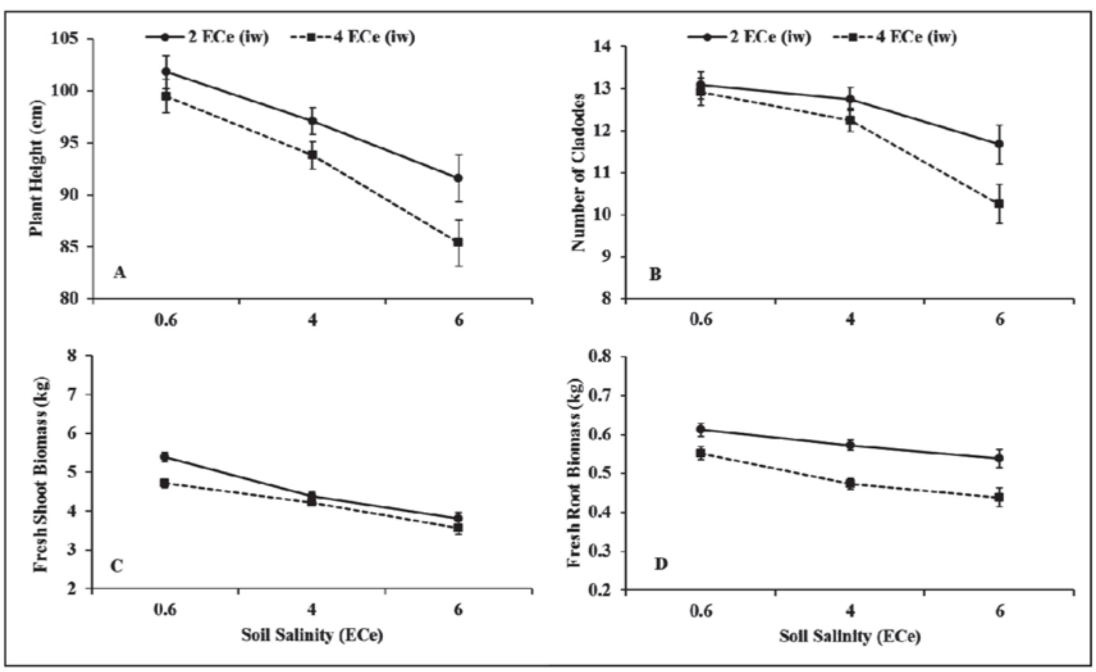

Fig. 2. Effect of soil salinity (ECe~ 0.6, 4.0 and 6.0 dS m^{-1}) and water quality (ECiw~ 2.0 and 4.0 dS m^{-1}) on (A) plant height, (B) number of cladodes, (C) fresh shoot biomass and, (D) fresh root biomass of *Opuntia ficus-indica*, after five years of growth. The vertical bars are standard error of means (SEm±) of respective mean values.

with the increase in salinity in this study could be ascribed to a strategy of *Opuntia* that favours survival rather than vegetative growth and, therefore, makes it more adaptable to adverse conditions. *Opuntia* is a drought tolerant crop, since even the smallest amount of water it absorbs is used efficiently (Snyman, 2004). It is able to do this due to its relatively shallow and horizontally spread root system and the ability, when other crops are not able to withdraw water from the soil at a very low moisture stage (Singh and Singh, 2003; Snyman, 2004). The root system differs from that of other plants as they develop xeromorphic characteristics which enable the plant to survive prolonged periods of drought (Sudzuki, 1995). This could also be the reason of higher sensitivity of roots to irrigation water salinity rather than soil salinity in contrary to the above ground parts (Fig. 2D).

Fruit characteristics

Length, diameter, weight, moisture (%), TSS (°B) and p/n (%) of fruit collected from four promising clones (1270, 1271, 1280 and 1287) were determined and presented in Table 1. It was observed that clone 1287 produced bigger fruits and, as such, higher fruit yield followed by 1271. Clone 1280 had more moisture content (91.39%) and hence more juicy than other types but lower in brix TSS (3°B) and hence low in sweetness. The lower moisture content in clones 1270, 1271 and 1287 provides tough texture to the fruits, hence better transportability. The brix TSS that is a measure of sweetness was higher in clone 1270 followed by 1271 (11°B and 10°B, respectively). The p/n ratio is also an important parameter to determine the taste of fruit and was higher in the latter two clones (Table 1.).

Fruit quality has rarely been investigated in relation to environment. The wide variability in yield most probably depends on orchard design and management, however, cultivar behavior in terms of plant fertility and productivity needs to be investigated in comparative trials, under different environmental conditions. Fruit size depends on seed number, cladode load, water availability, and ripening time (Nerd *et al.*, 1991; Inglese *et al.*, 1995). The sugar content plays a decisive role in defining fruit quality, since consumers favor sweet fruits. Sugars, mainly glucose and fructose, accumulate faster during the final weeks of flesh development and it is generally recognized that optimum total soluble solids (TSS) values at harvest should range between 13-15% (Barbera *et al.*, 1992).

Rating of cactus fruit

The ripe fruits of these clones were provided to a total of 527 persons for palatability analysis based upon their taste and sweetness. The taste evaluation group comprised doctors, scientists, advocates, students, technicians, and farmers. Individuals, varying in age from 28 to 50 years, were asked to give a score on a 0 to 10 scale. In 2008, total 115 persons rated the fruits and 18% of them gave a score of 8, or more; whereas 7% people did not like the taste and gave a score less than 5. In year 2009, total 169 persons rated the fruit and 19% rated it more than 8. Again in 2010, 16% people (243 respondents) rated the fruits above 8. The persons rated fruit less than 5 were 9 and 12% in 2009 and 2010, respectively. Majority of the people *i.e* 75% in 2008, 72% each in 2009 and 2010 rated the fruits between 5 to 8 (Table 2). Most of the people suggested improving it further for seedless character and more sweetness.

Table1. Fruit characteristics of different cactus clones planted at CSSRI, Karnal

Clone	Length (cm)	Diameter (cm)	Weight (gm/fruit)	Moisture (%)	TSS (°B)	p/n (%)
1270	6.5	3.6	54.5	84.08	11	4.31
1271	6.8	3.7	62.5	83.74	10	4.46
1280	6.8	3.2	49.0	91.39	3	3.42
1287	8.2	3.8	81.2	83.78	8	3.70
Mean	7.1	3.6	61.8	85.75	8	3.97

Table 2. Rating of cactus fruit based on sweetness and taste on a 0 to 10 scale by 527 respondents

Year (Respondents)	2008 (115)			2009 (169)			2010 (243)		
Scale	<5	5- 8	>8	<5	5-8	>8	<5	5-8	>8
Taste	3	90	22	14	117	38	13	188	42
Sweetness	4	88	23	6	122	41	17	181	45
Flavor	9	84	22	10	120	39	32	174	37
Ease in eating	13	76	26	26	131	12	34	169	40
Ease in handling	13	94	8	18	121	30	49	162	32
Per cent	7	75	18	9	72	19	12	72	16

Many species of *Opuntia* have been naturalized world-wide since the 15th century and are common in the subsistence agriculture of many communities in dry land areas. However, fruit consumption is still limited to local or ethnic markets, and cactus pear still has to go far before it becomes a major fruit crop world-wide (Inglese *et al*., 1995). Presence of thick, hard seeds in the flesh and spines on outer covering are the major constraints limiting the consumption of cactus pears.

Conclusion

Once established in salt-affected area with underlying poor quality water the edible cactus has potential to yield fodder and fruit. The plant is moderately tolerant to soil salinity and most of the growth parameters viz., number of sprouts, plant height and number of cladodes start showing sensitivity at or above EC_e 6.0 dS m^{-1} soil salinity. No significant effect of saline water irrigation found up to 4.0 dS m^{-1} (EC_{iw}) except the significant reduction in number of sprouts produced. The above ground biomass production was found sensitive to soil salinity level of 6 dS m^{-1}, while root biomass production was more sensitive to saline water irrigation rather than soil salinity. Finally, cactus can be given importance as a potential crop in dry regions as an alternative fruit crop and identifying salt tolerant clones (such as prickly pear cactus) might help in evolving suitable plant/variety for utilizing saline water for higher fruit production; fortunately these are also of medicinal value and need less measures of protection. For that fruit quality characteristic of promising edible cactus clones and their potential of acceptability as a palatable fruit among general public found very encouraging.

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